Chapter 9:

Tables and Figures

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List of Figures

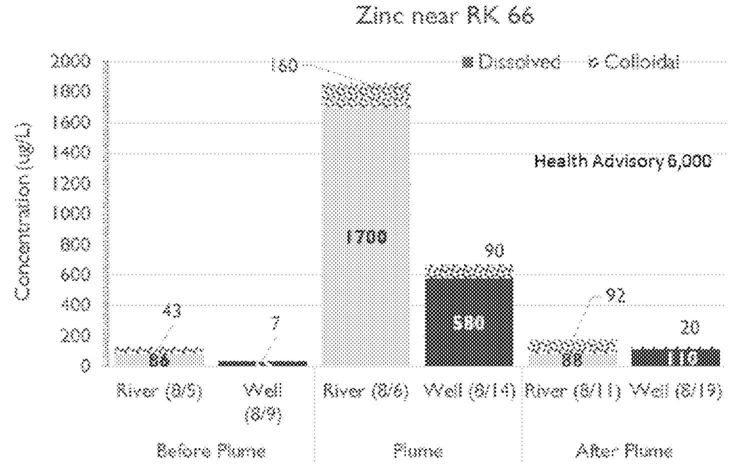


Figure 9-1. Empirical data of dissolved zinc concentrations at a mid Animas River community well (RK 66). For this community well, located 66 km downstream of GKM and 35 m from the Animas River, the surface water plume passed on 8/6 with observed dissolved zinc concentration 1700 ug/L. Three groundwater samples were analyzed for this well, on 8/9, 8/14, and 8/19. An elevated dissolved zinc concentration of 580 ug/L was reported for 8/14, which would be 8 days post river plume passage. We plot here observed river concentrations accounting for an 8 day delay, meaning 8 days prior to the well observation, suggesting segregation into before plume, plume, and after plume categories. Do we have a well signal, showing the delay from the surface water signal, consistent with well communication with the river and plume? Might computer modeling be helpful for understanding the possibility of communication of the well with the river plume? Data from CDPHE (2015).

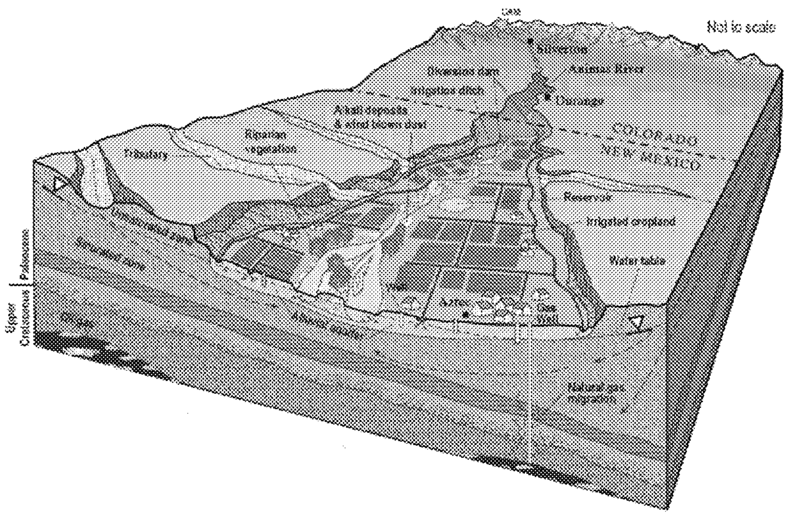


Figure 9-2. The shallow alluvial floodplain aquifer of the Animas River, with emphasis between Aztec and Farmington, NM (RK 170-180). The river is in dynamic communication with the shallow alluvial aquifer. The Animas River is a gaining stream on a regional basis and most of the time, with groundwater draining to the river. However, there are site specific and temporal situations where a river reach is losing water to the groundwater system. The ubiquitous presence of irrigation ditches and cropland has strong influence on the water table from summer to late fall. And the local water table determines whether a local stream reach is gaining or losing. After Timmons et al. (2016).

(a)

(b)

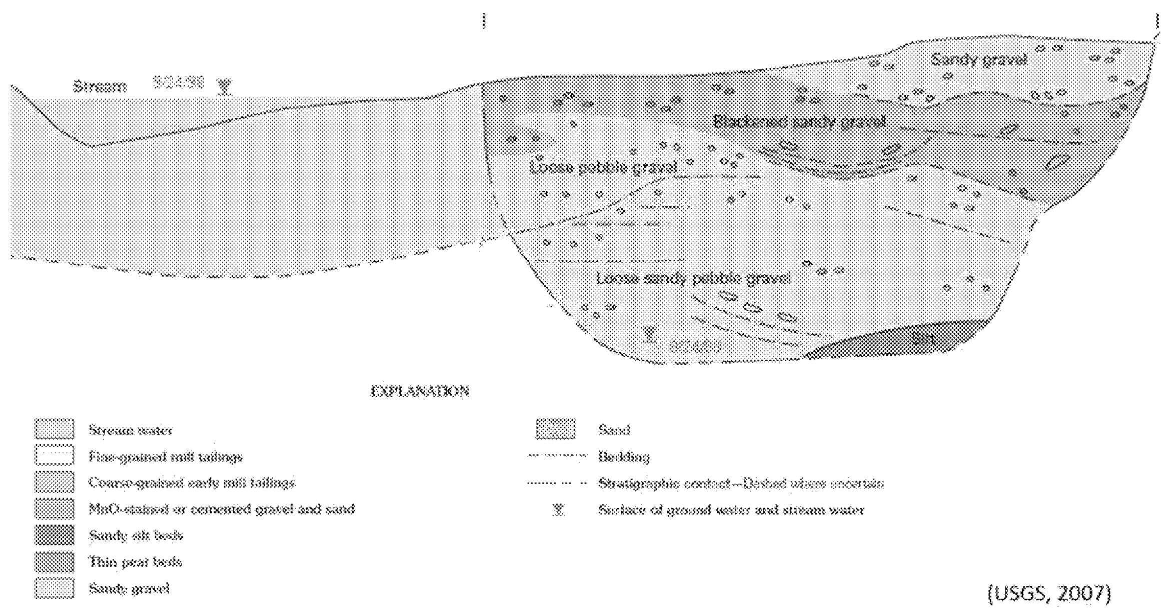


Figure 9-3. Animas River in floodplain near Eureka above Silverton, Colorado. (a) Google Earth image showing the braided dry channels and the location of the geologic cross section. (b) Generalized geologic cross section of the shallow floodplain deposits of the Animas River above Silverton (Vincent, Elliott, 2007). The shallow stratifications include pebble and sandy gravels.

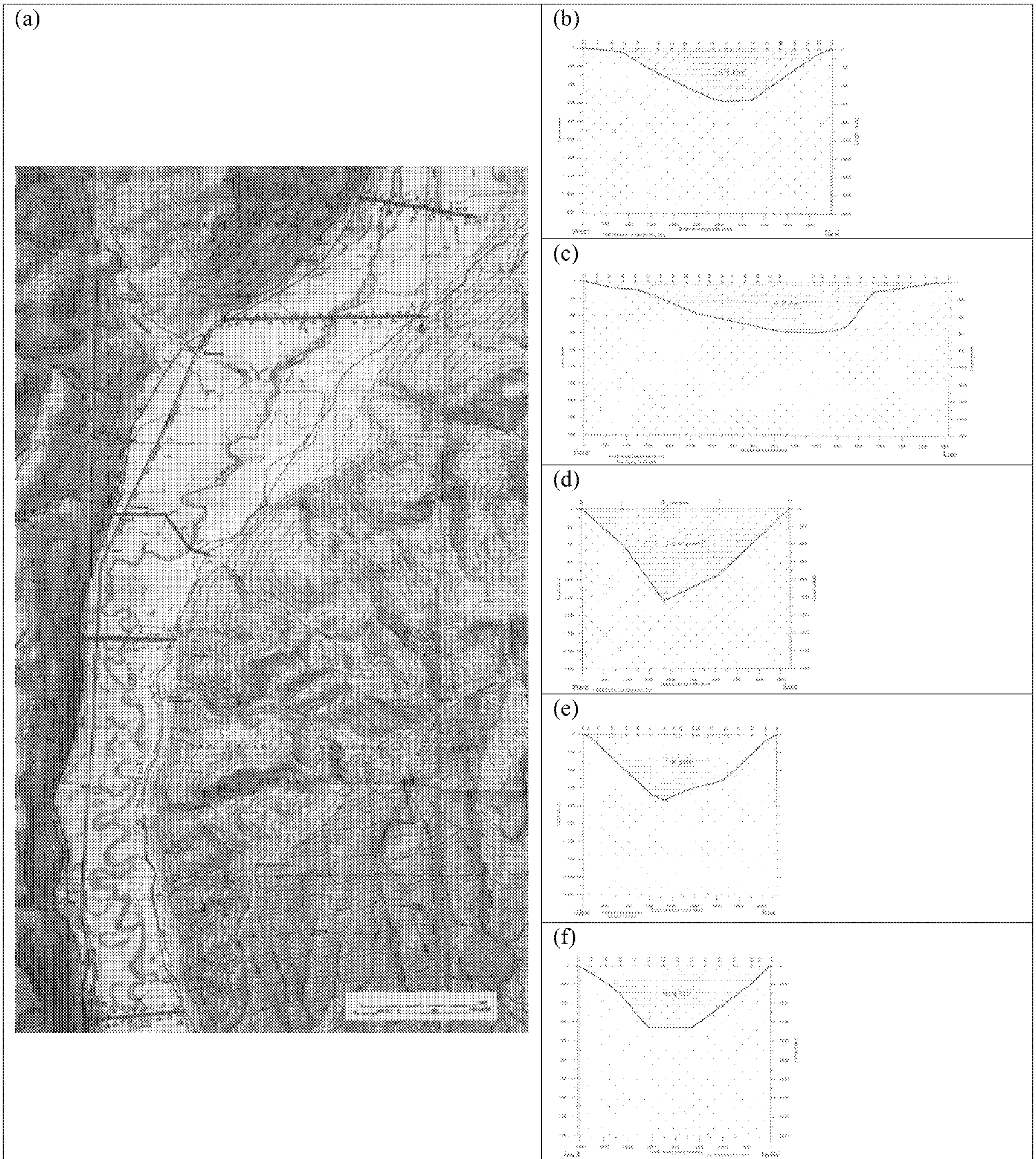
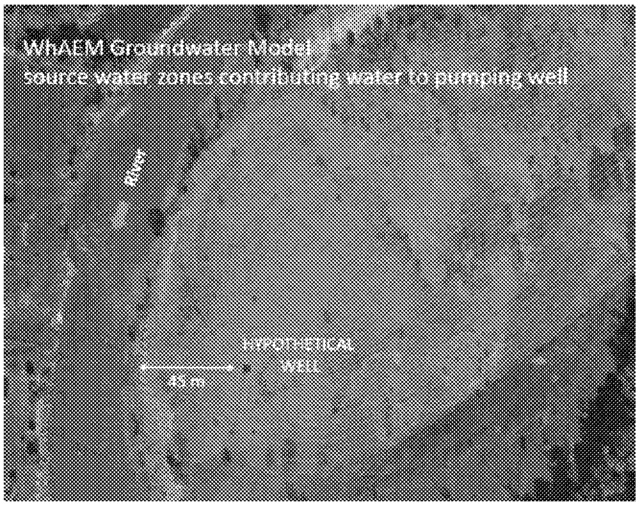


Figure 9-4. Geophysics modeling of the shallow floodplain aquifer base elevation based on a gravity survey. (a) map of the five gravity survey lines; (b) line 1 gravity and depth profile – 2 layer model; (c) line 2; (d) line 5; (e) line 3; and (f) line 4. The model suggests the depth of the aquifer ranges from 600 ft to 1000 ft. Data source: Hasbrouk Geophyics, 2003.

(a)



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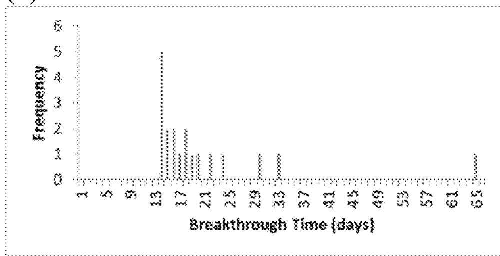


Figure 9-5. Demonstration of a pumping well capture zone and particle tracking breakthrough histogram using the WhAEM groundwater model of a hypothetical scenario. The well is located about 45 m from the river. (a) The well sources some of its water from the river (orange zone) and some from aquifer recharge and storage (blue zone). The source water capture zone is defined by 64 streamlines emanating from the well. 19 particles were released from the river boundary as suggested by the capture zone streamlines. (b) The time of arrival breakthrough (days) at the pumping well are reported in a histogram, with 5 particles arriving day-14 post leaving the river. The suggested peak river concentration is diluted to about 8% (5/64). Flushing of the aquifer takes at least to day-65. It is important to note that advective transport is steady state and does not account for dispersion or sorption or decay of solute.

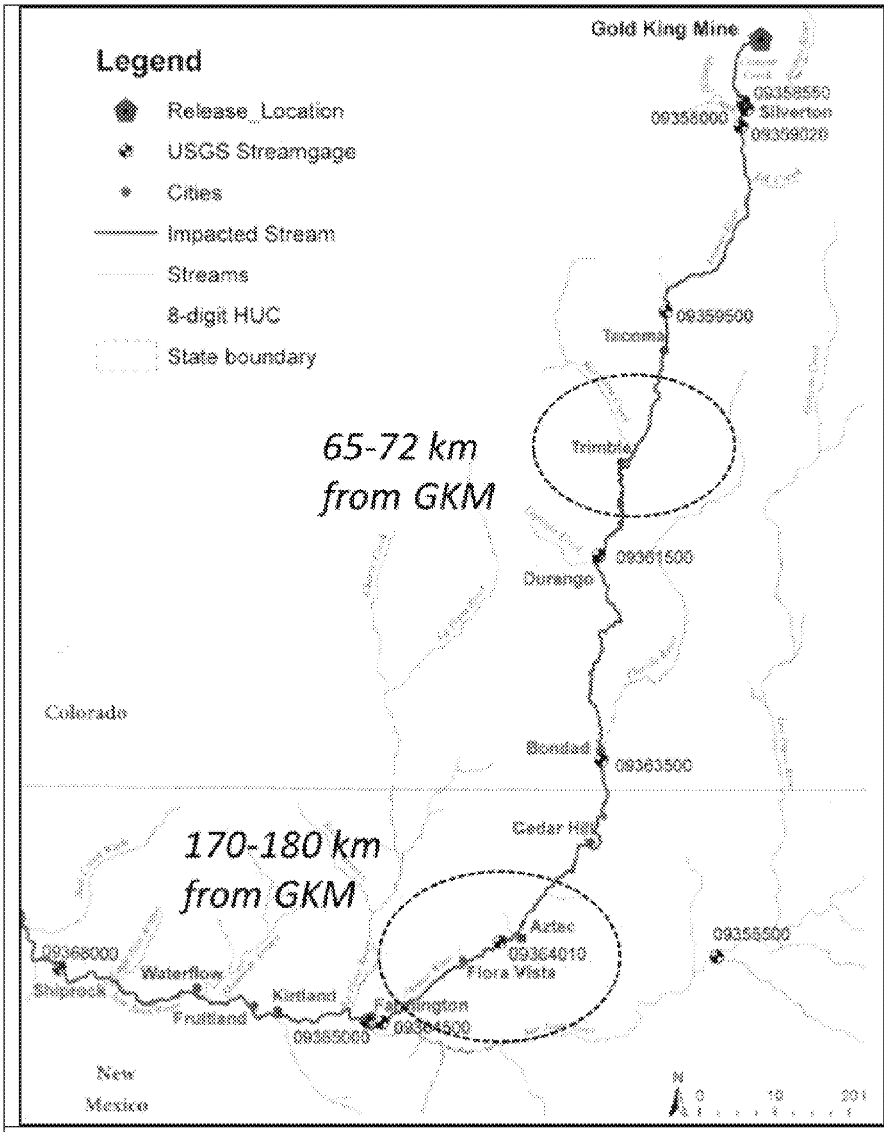


Figure 9-6. The mid Animas and lower Animas River clusters of community and private wells selected for groundwater modeling analyses. (1) the mid Animas River area between Tacoma and Durango, Colorado, 65-72 km downstream of the Gold King mine release site; and (2) the lower Animas River area between Aztec and Farmington, New Mexico, 170-180 km downstream of GKM.

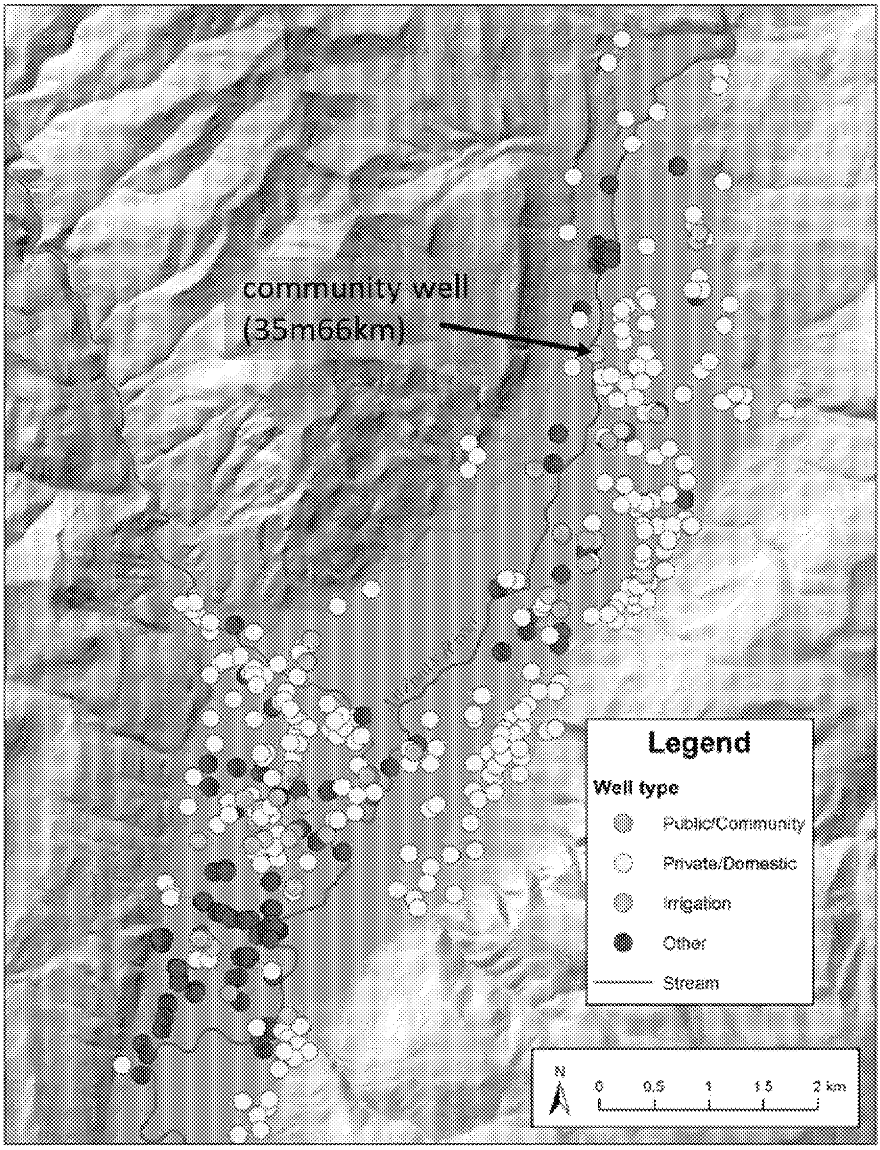


Figure 9-7. Water supply wells of the floodplain of the mid Animas River. The background is the topographic DEM and the hydrography of the USGS Hermosa Quad. Well data available from the Colorado DWR well permit search database. The community wells are represented by the orange circles.

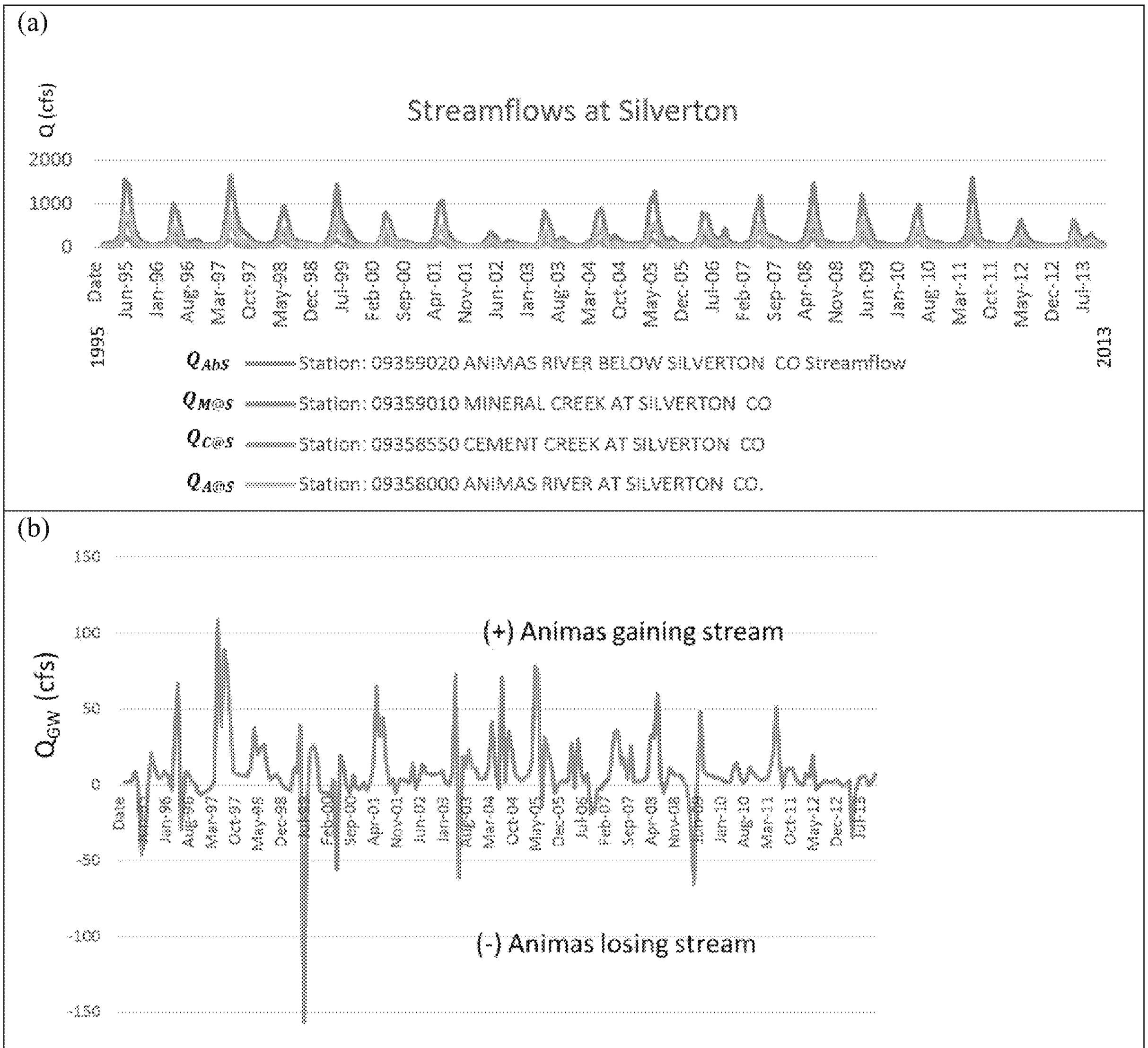
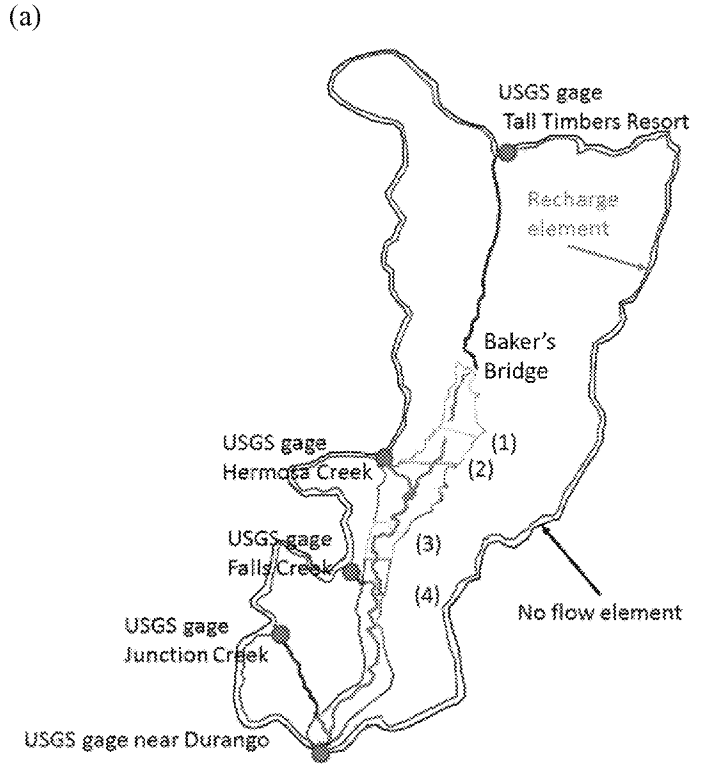


Figure 9-8. Streamflow analysis of the upper Animas River near Silverton, Colorado. (a) Streamflow hydrograph of measured discharge in cubic feet per second (cfs) of the Animas River at Silverton, Colorado. (b) Inferred groundwater inflows along the section of the Animas River around Silverton, CO, 1995-2013, where the water balance is $Q_{GW} = Q_{AbS} - Q_{A@S} - Q_{C@S} - Q_{M@S}$. The positive groundwater inflow implies that the Animas River is gaining groundwater most of the time. The negative exceptions suggest the river losing flow to the alluvial groundwater system, mostly in the summer. Graphics from the USGS Groundwater Toolbox.

Table 9-1. Conceptual Complexity and Groundwater Model Selection

	Conceptual Complexity	GFLOW	MODFLOW
1.	Single Layer aquifer (piecewise homogeneous properties, horizontal base elevations, point sinks for wells, line-sinks for rivers, area elements for zoned recharge and aquifer properties)	☑	
2.	Dupuit Forchheimer assumption (neglect resistance to vertical flow; hydraulic heads constant with depth, horizontal 2D flow)	☑	
3.	Non-time variant (steady state) stress and flow	☑	
4.	Time-variant (transient) stress and flow		☑
5.	Three dimensional flow		☑
6.	Particle tracking (reverse – capture zones; forward – breakthrough response)	☑	☑

(a)



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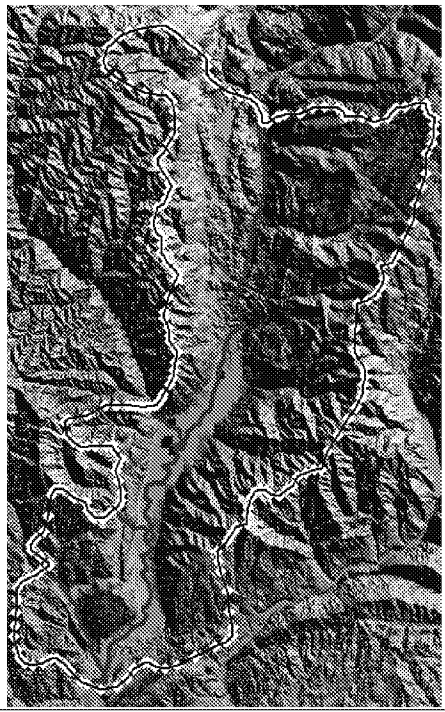


Figure 9-9. GFLOW layout of analytic elements for the mid Animas River floodplain groundwater model. (a) A no flow boundary is maintained at the catchment boundary or drainage area between the USGS gage on the Animas River at Tall Timbers resort, and the USGS gage on the Animas River near Durango. The aquifer base elevation is considered no-flow in the GFLOW model. The gravimetric estimate of aquifer thickness occurred at each of the scan lines. These were used to parameterize a stepping base representation in the GFLOW model. (b) USGS NED 10m resolution and the topographically defined catchment between USGS gage stations at Tall Timbers Resort and Durango, Colorado. The alluvial floodplain shows up in light blue-green.

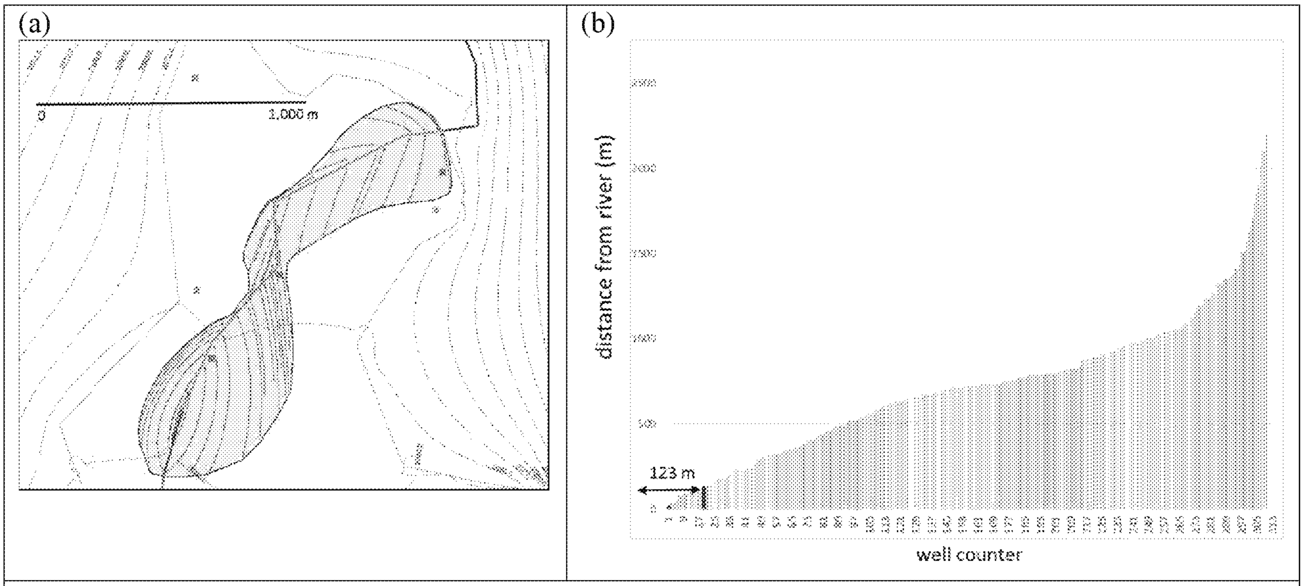


Figure 9-10. GFLOW model of the mid Animas River floodplain near Baker's Bridge (RK 65-72) showing groundwater-surface water interactions for the averaging period August-October 2015. (a) Hydraulic head contours (m) are shown as dotted lines and the river flow is north to south. Model calibration is discussed in Appendix D. The gaining sections of the river are colored black; the losing sections shown in green. Forward particle traces are shown in red, with residence time limited to 90 days time-of-travel. Note there are three private domestic pumping wells located inside the "hyporheic" zone colored light red. (b) The bar graph shows the distances of wells from the river of over 300 wells. Distances ranged from 10m to over 2000 m. The GFLOW model found that only three wells (including 5 community wells) in the mid Animas River area, and distances of the wells from the river ranged from 10-123 m. There were many other wells within 123 m of the river that the model suggested do not source river water. Therefore distance from the river alone is not predictive of well sourcing from the river. Geomorphology and the location of losing sections of the river are factors. The model suggests that the Baker's Bridge area where the Animas River leaves the mountain pass and enters the floodplain valley has groundwater seeping into the aquifer.

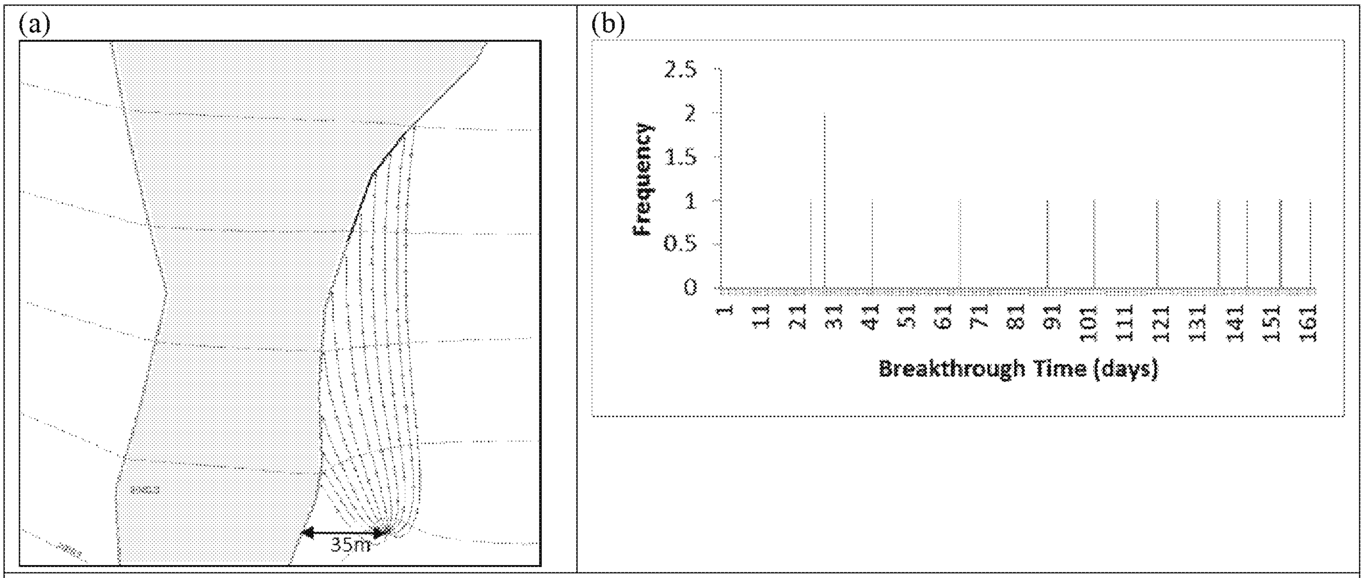


Figure 9-11. GFLOW capture zone and solute breakthrough histogram for a mid Animas River community well. GFLOW analysis of mid Animas River community well (35m-66km), high pumping (Qw= 2,616.5 m3/d) and low porosity (n=0.2) (a) particle tracking with 12 forward pathlines; (b) time of arrival breakthrough (days) are reported in a histogram, with a particle arriving in 25 days. Breakthrough time with same pumping but higher porosity (n=0.35) has a particle arriving in 44 days. Suggested peak river concentration is diluted to about 17% (2/12). Flushing of the aquifer in about 160 days. Full sensitivity analysis on area recharge, hydraulic conductivity of aquifer material, and pumping rate of well is described in Appendix D. Note that advective transport is steady (time invariant pumping and hydrology) and does not account for dispersion, sorption, or decay of solute.

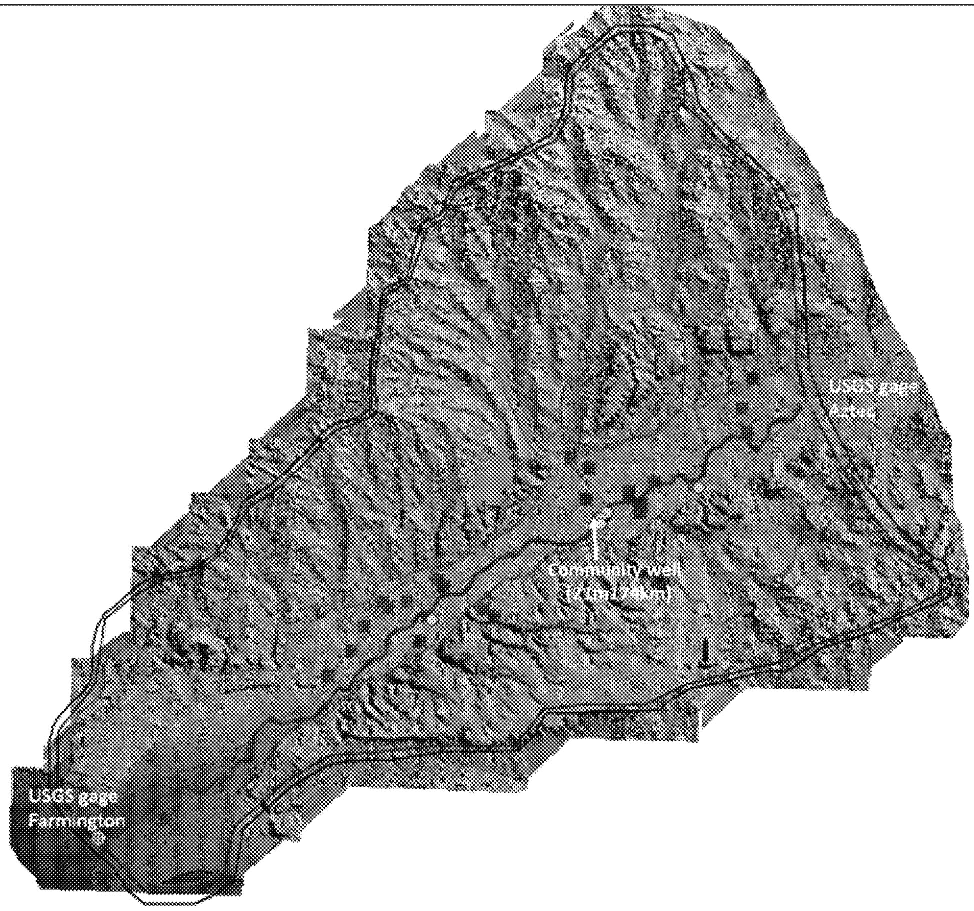


Figure 9-12. Community wells (orange) and select private wells (red) for the Lower Animas River floodplain study area. The catchment draining between the USGS gages at Aztec and Farmington was delineated as guided by the LiDAR DEM. Note the 21m174km community well. Data source: New Mexico Resource Geographic Information System (http://rgis.unm.edu/)

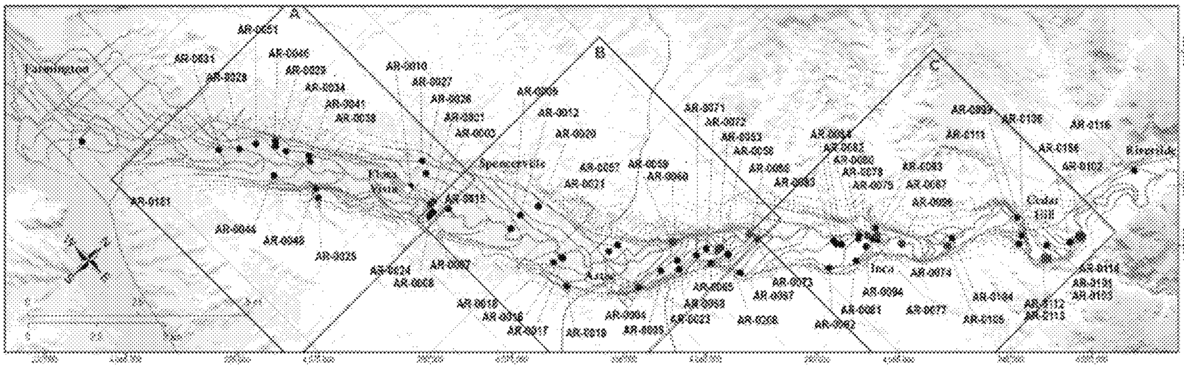


Figure 9-13. High resolution synoptic survey of the river water levels and well water levels in the lower Animas River floodplain, January 2016, between Riverside and Farmington, New Mexico. The wells were geospatially located using hand-held GPS. A high resolution LiDAR DEM was used to estimate land surface elevations. Data collection supports the New Mexico Bureau of Geology and Mineral Resources Aquifer Mapping Program (Timmons et al, 2016). The wells with negative gradient (shown as red dots) indicated segments of the Animas River that were losing river water to the aquifer.

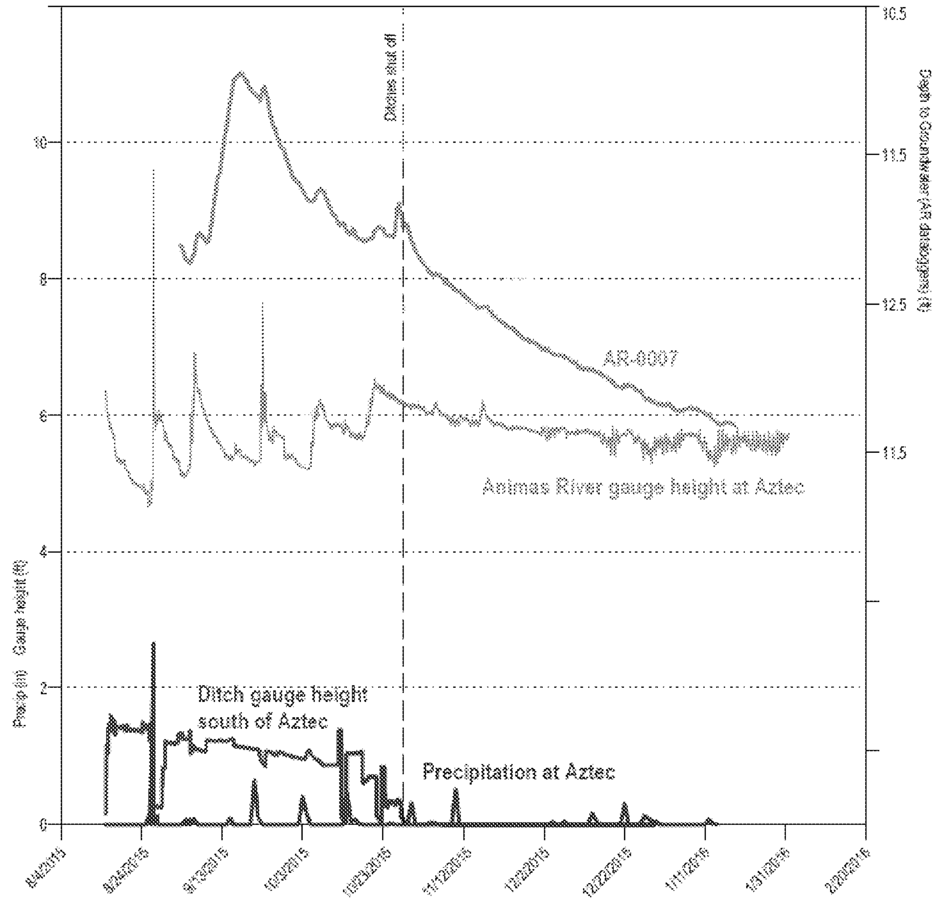


Figure 9-14. Hydrographs from Aztec area including a well with continuous data recorder plotted with influences from precipitation and Animas River stage and ditch gage height. Well AR-0007 is located on the south side of Aztec, is 32 ft deep, and is located on the east side of the river. (modified from Timmons et al., 2016).

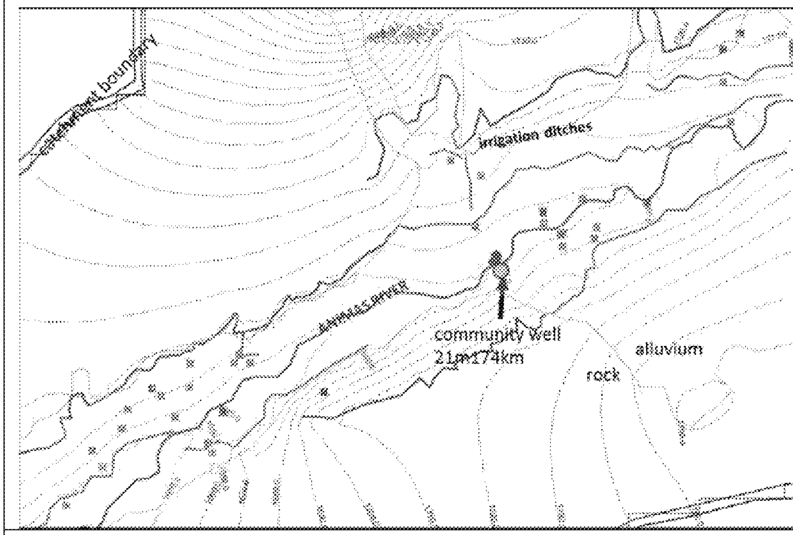
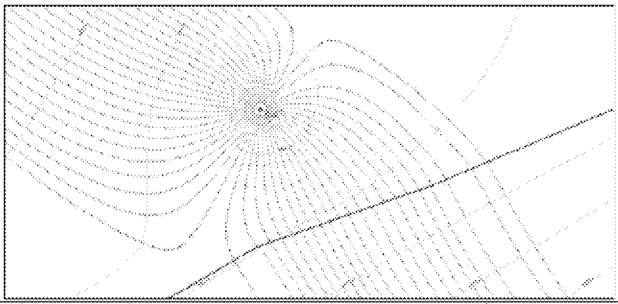
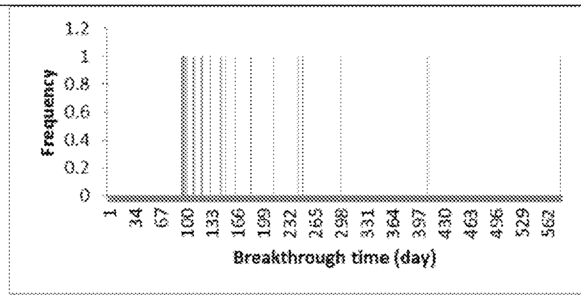


Figure 9-15. GFLOW model of groundwater-surface water interactions in the lower Animas River floodplain between Aztec and Farmington, New Mexico (RK 170-180) for the averaging period August – October 2015. Model calibration is described in Appendix D. Effective areal recharge is 0.21E-4 m/d. Rock hydraulic conductivity is 0.035 m/d and alluvium hydraulic conductivity is 2.2 m/d. The river and irrigation ditches are represented as line-sinks. The private and community wells are represented as point sinks. The 90 day capture zones of the wells are too small to be seen at this scale. The model suggests only the 21m-174km community well pumping at a maximum rate of 817.6 m3/d sources from the river.





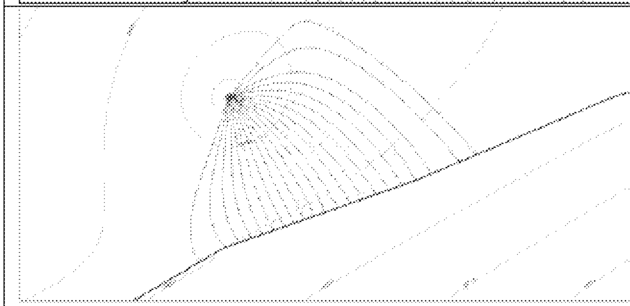


Figure 9-16. GFLOW capture zone and solute breakthrough histogram for lower Animas community well. GFLOW analysis of Lower Animas River community well (21m-174km), high pumping (Qw=817.6 m3/d) and low porosity (n=0.25). (a) capture zone delineation with 48 reverse streamlines; (b) particle tracking with 21 forward pathlines; (c) time of arrival breakthrough (days) are reported in a histogram, with a particle arriving in 94 days. Breakthrough time with same pumping but higher porosity (n=0.35) has a particle arriving in 131 days. Suggested peak river concentration is diluted to about 2% (1/48). Flushing of the aquifer in about 565 days. Note that advective transport is steady (time invariant pumping and hydrology) and does not account for dispersion, sorption, or decay of solute.

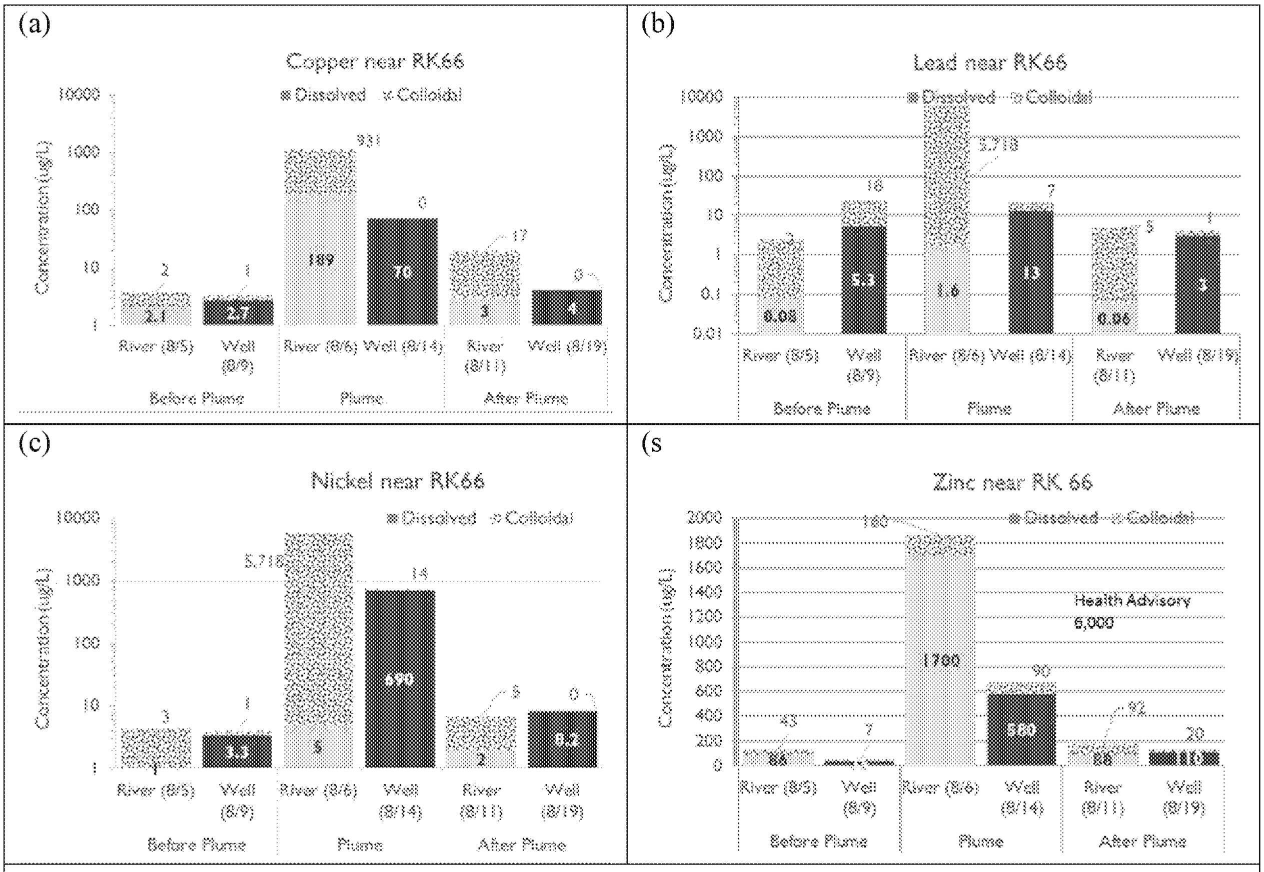


Figure 9-17. River and well dissolved and colloidal metals concentrations around RK 66 of the mid Animas River in Colorado. The data is organized into before, during, and after plume time windows assuming the peak river plume passed the location on 8/6 and a potential 8 day lag in transport in the groundwater system before arrival at the well.

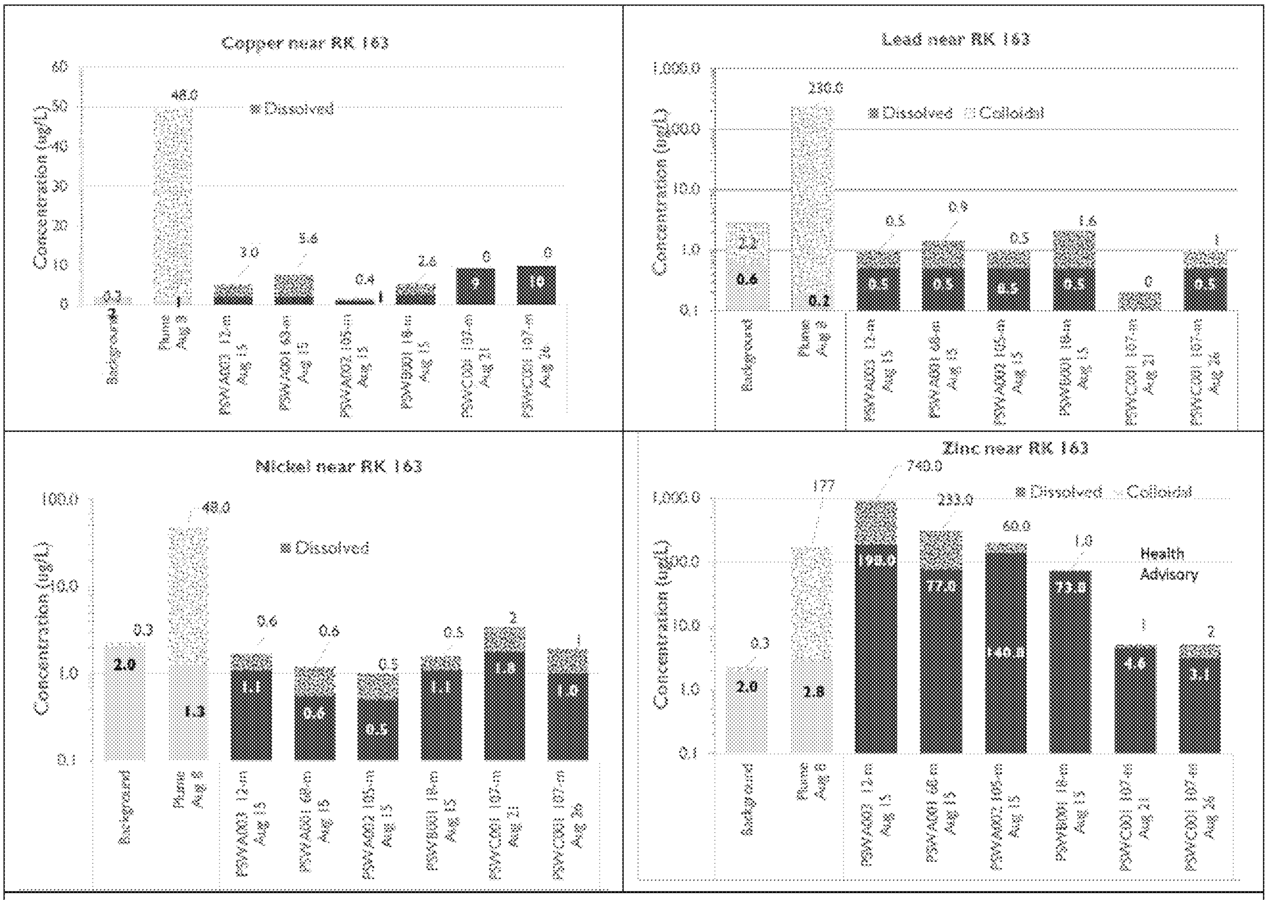


Figure 9-18. River and well dissolved and colloidal metals concentrations around RK 163 of the lower Animas River in New Mexico.